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An Analysis of the Current Status of Lead-Free Soldering. A Summary Report

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Approved on behalf of the Managing Director, NPL, by Dr C Lea, Head of Centre
for Materials Measurement and Technology.

INTRODUCTION

Lead (Pb) is a major constituent of solder which is used extensively within electrical and electronic equipment and there are environmental concerns over the amount ending up in land-fill. As a result attention has been increasingly focused on the potential of Pb-free soldering which can also provide improved reliability and mechanical strength. Some major companies are already using the green image of Pb-free products to promote their products successfully.

The publication in 1998 of the second draft of a proposal for an EC Directive on WEEE (Waste from Electrical and Electronic Equipment) has brought about a sharp focusing of attention. Although principally about recycling, the draft contains clauses aimed at banning the use of Pb in certain categories of electrical and electronic equipment. There is also a proposal to ban halogenated flame retardants used in the manufacture of the bare circuit boards and equipment housings.

The drive to reduce the level of use of hazardous materials is not new of course. For example lead in domestic water pipes and plumbing solders, petrol, paint and fishing weights etc has long been the centre of environmental and green pressures.

Printed circuit boards (pcbs) pervade every form of electronic equipment and are therefore vitally important for a vast range of products. Any change in soldering technology to Pb-free materials, would therefore have major implications for the industry, not only in the UK and Europe, but world-wide, involving many sectors including computers, white goods, brown goods, telecommunications, and other electronics.

The possibility of a change to Pb-free soldering has highlighted a whole series of questions relating to awareness and dissemination of existing information, materials availability, soldering technology, implementation of any new technology, added costs, and competitiveness not only within Europe but world-wide, especially with the US and the Pacific Rim countries. Moreover the timescales involved leave little room for manoeuvre. Japanese companies are now beginning to market lead-free products, and many intend to convert to lead-free technologies within the next two years. Furthermore, the proposed EC legislation mentions a phase-out of lead before 1.1.2004.

Clearly the first step in evaluating the implications of any change to Pb-free solders, is the accumulation, evaluation and dissemination of as much relevant data as possible, irrespective of where they have been generated, whether they are related to aspects of materials, technology, timescales, finance, competition etc. It is sensible that this step is taken quickly as the essential first stage in providing the help anticipated by the industry.

This report presents a summary of a short two months project commissioned by the DTI for NPL and ITRI to collaborate on a data gathering and preliminary dissemination exercise. Although the full report ("*An Analysis of the Current Status of Lead-free Soldering*" - see footnote*) contains many details of the key aspects associated with lead-free soldering technology, it is unlikely to be complete, since of necessity the project was short and quickly implemented. But it does provide a substantial basis on which to build, as and when other information, views, legislation etc become available. This summary report provides a flavour of the contents of the full report.

OBJECTIVES AND APPROACH

The main objectives of this project were:

- (a) *to gather as much relevant information as possible within the timescale*
- (b) *to review and analyse the information, and generate a report to be submitted to the DTI*
- (c) *to undertake the first steps in dissemination e.g. by generating summaries suitable for widespread dissemination via existing NPL and ITRI dissemination routes*
- (d) *to suggest the nature of any necessary further steps required by the UK industry to enable it be able to respond and comply with any proposed legislation*

The main activities have been a desk-top study, discussions with key industry/technology experts (individually and corporately), to determine the current industry status vis-à-vis Pb-free soldering issues arising from the proposed legislation, and the preparation of reports for widespread distribution.

The project was divided into eight sections:

General Level Of Awareness

This section was geared towards assessing the general level of awareness currently exhibited by UK companies, especially the SMEs, in the affected sectors. The primary vehicle used was a questionnaire sent to over 4000 people. Where possible and appropriate, the questionnaire was supplemented with a telephone contact to obtain additional or explanatory information. A full analysis of the returns is included in the report.

* **An Analysis of the Current Status
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R&D Projects

In this section the work was directed at ascertaining what relevant R&D projects have been, or are being carried out in the UK, and where possible, in non-UK countries. Clearly confidentiality considerations have been taken into account. The names of major sponsors of the R&D projects together with summaries of key projects have been incorporated in the report.

Pb-free Materials Availability

The origin, sourcing and availability of potential lead-free solders and their constituent elements have already been the subject of ITRI work. That work has been updated especially regarding information on lead-free solder availability in all forms that will be required (wire, bar, paste etc), and on listings of lead-free board coatings' suppliers and any information on component suppliers. Comments on the properties of various alloys and availability of low and high temperature alloys are included.

Pb-free Soldering Technology

The work has focused on lead-free processes aimed at a direct replacement for the mainstream (63/37 or 60/40) SnPb alloys. Ascertaining what technology exists, its maturity, its wider applicability, is a non-trivial exercise, and in such a short project the information is of necessity far from complete. But efforts have been made to highlight the issues surrounding implementation of each technology, the cost implications in changing the technology (solder materials costs, equipment modifications, qualification exercises etc). Particular implementation issues discussed are technology, logistics, availability, inspection, rework/repair, design for the environment, reliability, and recycling.

Legislation

Since legislation, if enacted, will be a key driver for the change to Pb-free soldering, it is vitally important to know what the current UK and EC legislation is, what changes are planned and in what timescales, and what regulations apply in other areas and countries around the world. The latter is crucial for issues of competition. The views and results of initiatives taken by EMIF members (e.g. PCIF) have also been included.

Halogenated Flame Retardants

The uncertainty surrounding the future use of pcbs containing brominated flame-retardants is not strictly a Pb-free issue, but it is highlighted in the second draft proposal of the EC WEEE Directive. Hence information has been sought on the availability of pcb materials which do not contain brominated flame retardants, and of associated issues such as compatibility, temperature tolerance, likely costs.

International Perspective

The project has sought to ascertain some (but non-exhaustive) information relating to "who is doing what" around the world, as a means of determining some idea of the trends and developments in the technology, and the breadth of applications of new technologies. The

reasons for certain alloy choices by manufacturers already trialling Pb-free alloys have also been investigated.

Preliminary Dissemination

The gathering pace in the drive to reduce the use of lead, means that time is of the essence, and there will be a need to deliver information to the UK industry as quickly as possible. Moreover, if the legislation is confirmed in the EC Directive, the need for such dissemination will be significantly enhanced. Hence the first steps of this dissemination have been implemented and/or planned.

CONCLUSIONS

The main conclusions from this study are:

Lead-free soldering is technologically possible, but key implementation issues need to be addressed:

- in most cases, higher process temperatures are required than for SnPb solders, and this may be incompatible with *some* materials, components and equipment.
- equipment and processes will have to be modified in many cases to accommodate the higher soldering temperatures. More flexible reflow ovens provide a relatively easy way to switch to lead-free solder use. More difficulties may be experienced with IR ovens.
- the process windows for Pb-free soldering are narrower than for SnPb,
- careful optimisation of the soldering process is required with wave soldering to eliminate fillet lifting defects, especially with Bi-containing alloys and components with Pb-containing terminations. A simple diagram illustrating fillet lifting is shown in Appendix 5.
- the changeover to lead-free technology is more straightforward for reflow than for wave soldering due to a reduced probability of fillet lifting.
- in the case of wave soldering the preferred changeover sequence is to Pb-free boards and components BEFORE Pb-free solders, due to the problems associated with fillet lifting. The changeover sequence for reflow soldering is not as critical because of the much lower risk of fillet lifting.
- criteria for visual and X-ray inspection methods may need to be modified.
- problems of fillet lifting and poor reliability may occur with boards which have been initially soldered using lead-free technology, but which are subsequently repaired/reworks using lead-containing solders. Appropriate labelling should reduce the problem.

- in some cases, cleaning processes may have to be modified.

Many lead-free alloys are readily available, however there has been no universal drop-in replacement identified so far.

- Some specific alloys may be dropped into specific processes without significant problems.
- At the moment one of the most promising alloys for general purpose soldering appears to be that based on Sn-Ag-Cu. Other alloys with potential are Sn-0.7Cu, Sn-3.5Ag and Sn-Ag-Bi.
- No viable alternatives for the high lead, high temperature alloys have yet been identified.
- The availability of Pb-free solders and board finishes is not an issue, and can be sourced within Europe. Solders are available in all forms required, and whilst certain alloys are patented, other attractive alloys are available for free use. Many lead-free boards are in widespread use, and there are not expected to be any compatibility problems between these coatings and lead-free alloys.
- The availability of components with Pb-free finishes, generally supplied by the multi-nationals into a global market, may pose a problem, particularly in the short term. Some components are already available with lead-free coatings but supply is currently limited. Some sectors of industry are already moving towards the use of Pd-Ni terminations for reasons other than lead-free compatibility.
- All necessary fluxes are available, although it appears that little or no change in flux chemistry will be required.
- Indications on reliability so far are that joints made with the proposed replacement Pb-free alloys are at least as good as those made with SnPb.

The main barriers to implementation of lead-free soldering are;

- lack of information on any necessary equipment and process modifications.
- poor understanding within the SMEs of the issues and implications of changing to Pb-free technologies
- the availability of components with Pb-free finishes,
- absence of sufficient in-depth R&D results in the public domain.

- lack of information on the reliability of complex devices such as BGAs, μ BGAs, flip-chip attachments, etc.
- there are other related factors, which although not strictly barriers to implementation, do need to be taken into account, eg the lack of co-ordination of R&D effort into lead-free soldering, and cost, in the absence of restrictive legislation.

There is a huge variation in awareness between OEMs and SMEs.

- the apparent awareness of the SMEs is only superficial and not supported by detailed understanding of the issues, timescales and implications involved. Even with OEMs, whilst the awareness may be high at the technical level, senior management understanding, commitment and activity, are often surprisingly low.
- trade organisations, the trade press and scientific meetings appear to offer the most efficient channels for dissemination.

The two main drivers for a change to lead-free technology remain the “green” activities in Japan and the proposed EC legislation.

- many multi-national companies intend to change to lead-free technologies earlier than the WEEE Directive proposes. This change is not dependant on the EC legislation being enacted and will impact on sub-contractors and suppliers.

Alternatives to halogenated flame retardants are available.

- higher loadings of some of these compounds are required to achieve the required safety standards.
- these alternatives are expected to increase cost and may degrade other properties.

RECOMMENDATIONS

The results of this study clearly indicate the need to undertake *quickly* five major activities

- ***Establish a mechanism for helping industry comply with any legislation***

What the industry urgently needs is some authoritative direction and advice on what to do should the proposed legislation come into effect. It needs a recognised source, a *Centre for Industry*, to which it can turn for help, for consultation on implementation, timescales, costs etc. The absence of such a centre following the Montreal Protocol and the subsequent banning of ODSs for the cleaning of pcbs and precision components, resulted in turmoil in the

UK industry, which has even now not been fully resolved. There is a need to avoid a repeat of this situation if the lead ban comes into force. This needs cross-sector co-operation, a road-map of what the industry needs to do to comply (JEIDA has its own road-map for Japan). Just as importantly it needs government involvement to provide credibility and emphasise the urgency of the situation.

- ***Organise a co-ordinated awareness campaign***

Whether or not a Centre for Industry is established there is an urgent need to raise the level of awareness in the industry, particularly within the SMEs. Such a campaign needs to be co-ordinated using a cocktail of dissemination routes (meetings, seminars, workshops, “cook-books”, circulars, trade press articles etc). This could be launched with a circular from the DTI which would again provide some credibility. But an awareness campaign will only have a small effect if it is not supported by the other activities suggested here.

- ***Form an information network of relevant R&D projects***

The current situation in which there is a clear lack of knowledge about who is doing what, in what timescales with what deliverables etc, is clearly undesirable. This network would establish the nature of the on-going, or planned, R&D projects and act as an information exchange and dissemination vehicle.

- ***Undertake a collaborative programme aimed at generating credible reliability data***

A major barrier to the implementation of lead-free technologies is the lack of freely available data on reliability under a variety of service conditions. Some data to exist, but these are generally within the large OEMs, who are reluctant to put them in the public domain. What is required is a collaborative project (certainly involving the SMEs and RTOs) focused specifically at generating such data under the conditions experienced by the SME assemblers, who would be expected to undertake trailing within the project.

- ***Organise a co-ordinated approach to component availability***

The complex situation regarding component availability is a global issue involving many multi-nationals. The situation is more a political/commercial one rather than a technical issue. The UK, if not the European, market is relatively small and does not have the muscle to approach the suppliers to supply lead-free product to enable them to comply with any legislation. There needs to be a high level approach to the suppliers involving the government, trade organisations etc to resolve this issue.

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